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The central PNe populations of external galaxies with SAURON

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Abstract.
Thanks to SAURON integral-field observations we uncovered the Planetary Nebulae (PNe) populations inhabiting the central and nuclear regions of our galactic neighbours M32 and M31, respectively, and discuss the significant differences between their corresponding PNe luminosity functions in light of the properties of their parent stellar populations. In particular, we conclude that the lack of bright PNe in the nuclear regions of M31 is likely linked to the nearly Solar value for the stellar metallicity, consistent with previous suggestions that a larger metallicity would bias the Horizontal-Branch (HB) populations toward bluer colors, with fewer red HB stars capable of producing PNe and more blue HB stars that instead could contribute to the far-UV flux that is observed in metal-rich early-type galaxies and, incidentally, also in the nucleus of M31.

Keywords. ISM: planetary nebulae: general, galaxies: individual: (M31, M32)

1. Introduction

Planetary Nebulae (PNe) in external galaxies are mostly regarded either as tracers of the gravitational potential (e.g., Romanowsky et al. 2003) or as indicators for the distance of their galactic hosts (e.g., Ciardullo et al. 1989), with the latter advantage owing to the nearly universal – though not fully understood – shape of the PNe luminosity function (PNLF, generally in the [O III]λ5007 emission). Yet extra-galactic PNe can also be used as probes of their parent stellar population (see, e.g., Ciardullo 2006) and understanding in particular the origin of the PNLF is a puzzle that, once solved, promises to reveal new clues on the late stages of stellar evolution and on the formation of PNe themselves (e.g., Ciardullo et al. 2005; Buzzoni, Arnaboldi & Corradi 2006).

PNe originates from horizontal-branch (HB) stars that climb back the asymptotic giant branch (AGB) at the end of their helium-burning phase, when these stars leave the AGB and quickly cross the Hertzprung-Russell diagram on their way towards the cooling track of white dwarves (WD). For a population with a given age and metallicity, HB stars have nearly the same helium core mass ($\sim 0.5\,M_{\odot}$) but a range of hydrogen shell mass ($\sim 0.001 - 0.3\,M_{\odot}$), with the reddest stars having also the largest H-shells and originating from the most massive main-sequence progenitors. Only HB stars with a considerable H-shell ascend toward the AGB and eventually lead to the formation of a PN, whereas the bluest HB stars with little envelope mass head straight toward the WD cooling curve by evolving first to higher luminosities and effective temperatures (the so-called AGB-manqué phase).

According to this simple picture, galaxies with on-going star formation should show brighter PNe than quiescent systems where massive stars have long disappeared (e.g., Marigo et al. 2004), but in fact the PNLF of young and old galaxies are relatively similar. In particular, all extra-galactic PNe surveys indicate a common and bright cut-off for the

PNLF, which led Ciardullo et al. (2005) to suggest a binary evolution for the progenitors of the brightest PNe that would be common to different kind of galaxies. If galaxies seem to invariably host very bright PNe, their specific content of PNe - that is the number of PNe normalised by a galaxy bolometric luminosity - appears to vary with the metallicity of the stellar population. More specifically, Buzzoni, Arnaboldi & Corradi (2006) found that more metal rich galaxies show comparably fewer PNe, which also corresponds to larger far-UV fluxes. Interestingly, this may indicate that at a given mean stellar age, a larger metallicity would bias the HB population towards fewer stars with massive H-shell capable to lead to the formation of PNe, with a larger fraction of blue HB stars that contribute instead to the overall far-UV flux of their host galaxy (i.e. the so-called UV-upturn, Burnstein et al. 1988) as they follow their AGB-manqué evolution.

Within this context, we note that whereas our knowledge of both the shape and normalisation of the PNLF comes chiefly from the peripheral PNe populations of galaxies, both measurements for the stellar metallity and the UV spectral shape of galaxies pertain to their optical regions. This is because narrow-band imaging or slitless spectroscopy - the most common techniques employed to find extragalactic PNe - find it hard to detect PNe against a strong stellar background, whereas measuring the strength of stellar absorption lines or imaging the far-UV flux of galactic halos is prohibitively expensive in terms of telescope time. Such a dramatic spatial inconsistency needs to be resolved if we ought to understand the link between PNe and the properties of their parent stellar populations, in particular if we consider that such a connection may already not be entirely within our grasp, as Hubble Space Telescope (HST) observations for the UV color-magnitude diagram of M32 suggests (Brown et al. 2008).

2. PNe with Integral-Field Spectroscopy

Integral-field spectroscopy (IFS) can overcome the previous technical limitations and shed more light on the link between PNe and their parent stellar population by allowing to both explore the central PNe population of galaxies and measure the stellar metallicity of their halos. Indeed, IFS makes it possible to carefully model the central stellar spectrum of a galaxy and thus reveal the presence of PNe deeply embedded in it. At the same time, adding up all the spectra obtained by an integral-field unit effectively turns it into a large light bucket that allows to measure the strength of stellar absorption lines out to large galactic radii. For instance, using the `SAURON` integral-field spectrograph mounted on the 4m William Herschel telescope, Sarzi et al. (2011) more than doubled the number of PNe known in the optical regions of M32 in just 20 minutes of observations, whereas Weijmans et al. (2009) could map the stellar age and metallicity of NGC 821 and NGC 3379 out to 3 and 4 effective radii, respectively, by spending only few hours per galaxy.

3. Comparing the Central PNe Populations of M32 and M31

Following the work of Sarzi et al. for the central regions of M32, Pastorello et al. (2012, in preparation) carried a similar analysis of the nuclear regions of M31, further showing how IFS can detect PNe also in the presence of diffuse ionised-gas emission (as is often observed in early-type galaxies) and that for this purpose the `SAURON` data are just as good as narrow-band HST images of much higher spatial resolution.

Fig. 1 shows both the PNe detected by Pastorello et al. in the central 30pc of M31 and those found by Sarzi et al. in the optical regions of M32 (within one effective radius R_e), while also comparing their corresponding luminosity functions to the shape that the theoretical PNLF of Ciardullo et al. (1989) takes after accounting for the incompleteness

of our observations (red dashed lines). Already at first glance the PNe populations of M32 and M31 appear to be different, with the PNLF of M31 looking hardly consistent with the theoretical expectations and deficient in bright PNe. In fact, whereas a Kolgomorov-Smirnov test indicates that the incompleteness-corrected theoretical PNLF of Ciardullo et al. can be regarded as the parent distribution for the PNe found in the optical regions of M32 at an 82% confidence level, the same test returns only a 20% chance of that happening for the nuclear PNe of M31. Furthermore, even assuming that the PNe of M31 were drawn from such a standard PNLF, simulations like those presented by Sarzi et al.

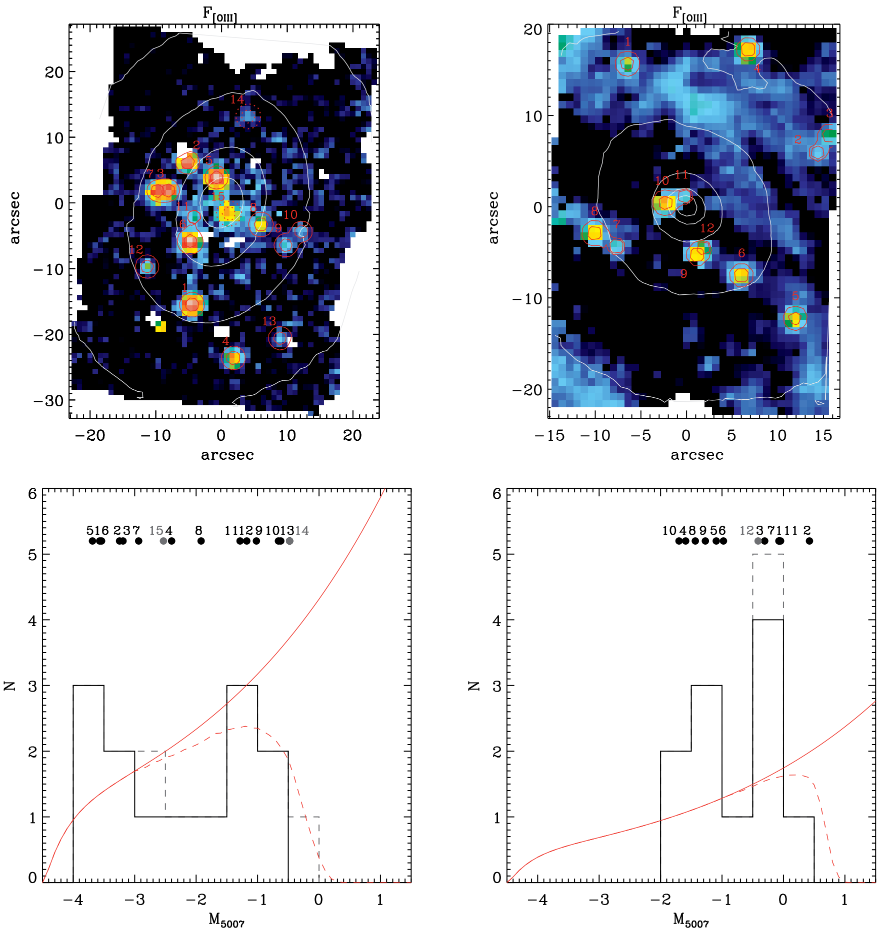

Figure 1. SAURON maps for the flux of the [O III]λ5007 emission (upper panels) from the central regions of M32 (left) and the nuclear regions of M31 (right) together with the luminosity function of the PNe found in them (lower panels). In the [O III] maps the white contours outline the galaxy stellar isophotes whereas the position of the detected PNe is shown by the red contours. The absolute magnitude of these PNe can be read in the lower panels, where the red solid and dashed lines also show the theoretical form of the PNLF (from Ciardullo et al. 1989) as it is and after accounting for the incompletness of our observations, respectively. Grey points and dashed histograms correspond to marginal PNe detections. In the case of M32, the models have been normalised to match the observed number of PNe to the number of objects that we would expect to detect according to the incompleteness-corrected PNLF model. For M31 the nuclear PNe population is unlikely to have been drawn from such a PNLF model, and the lines are shown mostly for an illustrative purpose and are normalised by simply assuming the same specific PNe density of M32.

would generate synthetic PNLFs with no bright PNe at all (i.e., within 2.5 magnitudes of the bright cutoff at $M_{5007} = -4.47$) only in 8% of the cases. It is therefore unlikely that the lack of bright PNe in the nuclear regions of M31 (confirmed also by the HST observations presented at this conference by Girardi et al.) is merely due to bad luck.

4. Connection with the Parent Stellar Population

It is interesting to consider such remarkable differences between the central and nuclear PNLF of M32 and M31, respectively, in light of the properties of the parent stellar population of such PNe systems.

Our `SAURON` observations encompass nearly the same amount of stellar light in these two galaxies and in both cases the stellar population is fairly old. However, the nuclear population of M31 is more metal rich than that of the central regions of M32. More specifically, our own `SAURON` stellar absorption-line measurements indicate a nearly Solar value of [Fe/H] ~ -0.2 for the average metallicity of the nuclear stars of M31, in line with what found in the centers of low mass early-type galaxies (e.g., as in `SAURON` survey; Kuntschner et al. 2006), whereas the optical regions of M32 display stellar metallicity values around [Fe/H] ~ -0.5, well below Solar standards and closer to what observed in the outskirts of more typical early-type galaxies (see, e.g., Weijmans et al. 2009). At the same time, is has long been known since the first low-resolution UV spectroscopic observations of Burstein et al. (1988) with the International Ultraviolet Explorer (IUE) that M31 shows stronger far-UV fluxes than M32 (within their central $\sim 20''$).

That the lack of bright PNe in the nuclear regions of M31 coincides with the presence of a UV-upturn and with a larger stellar metallicity than in the case of M32 supports the scenario advanced by Buzzoni, Arnaboldi & Corradi, whereby at a given mean age a more metal-rich stellar population would display a bluer HB population with fewer red HB stars capable of producing PNe and a larger fraction of blue HB stars that during their AGB-manqué phase would contribute to larger far-UV fluxes. Yet, our data further indicate, as intuition suggests, that such a HB bias would start by suppressing the reddest HB stars that lead to the brighest PNe, thus leading also to a change in the shape of the PNLF. It would be interesting to see if even more metal-rich stellar systems show such a faint PNLF cutoff, as found for the first time by our `SAURON` observations in the nuclear region of M31 (see Pastorello et al., for details).

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